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Quantifying Carbon and Distributional Benefits of Solar Home System Programs in Bangladesh

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Abstract

Scaling-up adoption of renewable energy technology, such as solar home systems, to expand electricity access in developing countries can accelerate the transition to low-carbon economic development. Using a purposely collected national household survey, this study quantifies the carbon and distributional benefits of solar home system programs in Bangladesh. Three key findings are generated from the study. First, dissemination of solar home systems brings about significant carbon benefits: the total carbon emissions avoided from replacing kerosene use for lighting by solar home systems in non-electrified rural households was equivalent to about 4 percent of total annual carbon emissions in Bangladesh in 2007. This figure increases to about 15 percent if the grid-electricity generation is used as the energy baseline to estimate the carbon avoided from the installation of solar home systems. Second, solar home system subsidies in rural Bangladesh are progressive when the program is geographically targeted. Third, there exists a market potential for solar home systems in many rural areas if micro-credit schemes are made available and the propensity to install solar home systems is very responsive to income, with a 1-percent increase in per capita income increasing the probability of installing solar home systems by 12 percent, controlling for other factors.

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Quantifying Carbon and Distributional Benefits of Solar Home System Programs in Bangladesh

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1. **Introduction**

Providing electricity to over a quarter of the world's population currently without access has become a policy priority of development agencies. This is largely motivated by the increasing recognition of the broad range of economic and social benefits associated with electricity access. In the face of climate change, advances in an array of renewable technologies, including wind, solar, biomass and hydroelectricity, present an opportunity for developing countries to expand electricity access while accelerating the transition to a low-carbon development path.

A range of off-grid options, in particular solar home systems (SHS)[2], make it possible to provide the basic electricity needs of households, local communities and small businesses in rural areas where grid-electricity is not an option in the foreseeable future. The dissemination of SHS over the past two decades has improved the quality of life and livelihoods of many people in remote areas, through better quality lighting, extended working hours and powering small appliances such as mobile phones. These benefits have been achieved with near zero carbon emissions while also reducing the use of fossil fuels, such as kerosene for lighting and diesel for battery-charging.

Scaling-up the adoption of low-carbon energy technologies in developing countries must be part of the global efforts to reduce the devastating risks posed by climate change. According to the IEA projections, between 2020 and 2030 developing country emissions of carbon from energy use will exceed those from developed countries, as more than three quarters of the global increase in carbon-dioxide (CO_2) emissions will come from developing countries (IEA, 2007). Reducing emissions in developed countries alone will not be sufficient to achieve the goal of limiting a global average temperature increase to no more than 2^o C (OECD, 2008).

This means that the bulk of the additional investment for climate change mitigation, in particular in the clean energy sector, should flow into developing countries. Responding to this need, a large number of bilateral and multilateral funds and financial mechanisms, such as the Clean Development Mechanism (CDM), have been established following the Bali Action Plan, which calls for mitigation actions by developing countries to be supported and enabled by technology, financing and capacity building from developed countries (Doornbosch and Knight, 2008). Also, financial resources, both from the public and private sectors, have been channeled into the clean energy sector at an increasing rate[3], providing an enormous opportunity to integrate climate change mitigation into development.

However, maximizing the carbon mitigation and development impact of this expanded carbon finance depends on the efficient and equitable allocation of these resources. While renewable energy programs, in particular SHS, have been implemented in many developing countries over

[2] A typical SHS that consists of a PV module with a 20-year life cycle, a controller and a rechargeable lead-acid battery, can be easily manufactured to good quality standards in many countries. The prices of SHS have been declining rapidly over the past few years, with the average price of a SHS in the range 40-50 Wat peak (Wp) being about $200-300

3 The World Bank group has seen a steady increase in the share of financing committed for low carbon renewable energy and energy efficiency, rising to about 40% in 2007, from about 13% in 1990-94, with about 0.65 million SHS installed across 23 countries by 2007

the past two decades by international institutions and NGOs, studies that focus on the carbon benefits as well as the distributional impact of subsidies based on large scale household surveys are extremely lacking.

This study aims to fill this gap using the first available national household survey that collects data on SHS installation in rural Bangladesh. Bangladesh is one of a few countries that have made significant progress in providing electricity access to rural population through SHS. The SHS programs that were financed from Global Environment Facility (GEF) and International Development Assistance (IDA) had installed over 300,000 SHS (accounting for about 1.6 % of non-electrified rural households) in rural Bangladesh by 2009. This study focuses on (1) the quantification of the carbon benefits, particularly on kerosene displacement; (2) SHS affordability; and (3) the distributional consequences of SHS subsidies.

This paper is structured as follows: section 2 reviews the development of SHS dissemination in LDCs. Section 3 summaries the progress of rural electrification in Bangladesh. In section 4, we present the statistical summary of the 2005 national household survey. Section 5 presents methodology and results in the above three areas. Section 6 concludes.

2. SHS dissemination in less developed countries

Despite technology maturity and the constant decline in SHS prices, the current level of SHS dissemination among rural populations is low. According to the Global Status Report 2009, out of the 400 million households who lacked access to grid electricity in 2007, only about 2.5 million received electricity from SHS.[4] A recently published IFC report, entitled "Selling Solar ", summarizes the lessons from more than a decade of experience in SHS dissemination in developing countries and concludes that many IFC programs financed through GEF have not been able to create sustainable SHS business in rural areas.

Several factors underlie the slow progress in SHS dissemination for rural electrification. These include lack of information about SHS and grid-extension plans, lack of financial resources for SHS businesses and consumer financing programs, and lack of trained staff and human resources for system delivery and maintenance (Kaufman, 2000 and IFC, 2007). But a more important factor is likely to be the lack of supporting policies and political commitment that can critically influence the transfer and dissemination of renewable technologies for rural electrification. For example, many pricing policies, including subsidies to kerosene and existing fossil fuel-based electricity generation and import taxes on SHS components, are biased in favor of existing utilities, hindering the wider dissemination of alternative renewable technologies (Miller et al, 2000).

While a few countries in Africa and Latin America made some progress in SHS or solar lanterns for rural electrification, the growth of SHS adoption in recent years has been concentrated mainly in Asia, including Bangladesh, India, Sri Lanka, Nepal, Thailand and China. Government

[4] For almost 20 years, the World Bank Group, working with many developing country governments with financial support from many donors, in particular from GEF, has supported over 25 countries in SHS dissemination, with over 1 million SHS installed in rural areas (IFC Report, 2007).

and international donor programs have actively supported SHS market development and dissemination in these countries by financing micro-credit programs to overcome the affordability issue, as well as supporting local community organizations to develop human resources and build institutional capacity to maintain quality services to the end-users (Ghosh et al, 2002). The experience from these countries, in particular Bangladesh, highlights the critical role played by active public policies to support the private sector development in the initial phase, through financing, capacity building for institutions and human resources, until a critical mass is reached for scaling up SHS dissemination (Nieuwenhout et al 2001).

Ultimately, policy decisions on how to expand rural electrification should be made in the context of local conditions and there is no one-size-fits-all model for all countries. Even within a country the decisions can be location specific. But these decisions must be based on evidence and not influenced by political agendas and interest groups. From carbon emission and equity perspectives, promoting SHS dissemination in rural areas is likely to be a desirable off-grid option for rural electrification in the short to medium term when grid-electricity may not be an economically viable option.

3. Bangladesh rural electrification

While Bangladesh has made impressive progress in expanding rural electrification, its electrification rate still lags behind other countries in South Asia. Between 2000 and 2008, the rural electrification rate increased by only about 14 percentage points to 34% in comparison to South Asia with an increase of 18 percentage points to 48 % over the same period.

The Bangladeshi government has set a target of bringing the entire country under electricity by 2020 with improved reliability and quality of electricity supply. However, achieving this target requires effective measures that can overcome two major constraints currently faced by the electricity sector. First, while per capita electricity generation capacity in Bangladesh is among the lowest in the world (at about 165 KWh per year), the demand for electricity is growing at a rate of over 500 MW per year due to population growth and rapid increase in demand for electrical appliances and increased industrialization (World Bank, 2009). As a result, frequent outages are common.

Second, the majority of the rural population lives in areas that are far from the national electricity grid. Without large subsidies the remote rural households cannot afford the cost of the grid expansion. Even if these households were connected to the grid, the insufficient generation capacity would lead to disproportionate load shedding in rural areas. Realizing that grid-electrification is not an economically feasible option, the government has taken a dual-track approach to expanding rural electrification: (1) expanding the electricity distribution grid to connect new consumers, and (2) making SHS available to households and promoting biomass projects to electrify village markets, small enterprises, and households (World Bank, 2009).

A significant amount of financial and technical assistance from the government and development agencies has been channeled to expand rural electrification in Bangladesh. The World Bank project, Rural Electrification and Renewable Energy Development (RERED), started in 2002 with total funding of $298 million, is part of these efforts. RERED aims to expand rural electrification through both grid-extension and renewable sources. The success, in particular in SHS dissemination in rural areas, had led to a request from the government for additional financing of $130 million in 2009, with $100 million earmarked for scaling-up SHS installation and other renewable energy based mini-grids in rural areas.

The implementation of SHS programs was carried through two different delivery models. The first model is implemented by the Rural Electrification Board (REB), the state-owned utility responsible for grid-electrification in rural areas. It was tasked to disseminate SHS through the fee-for-service SHS program, whereby the system would be installed and owned by REB and households would pay a monthly fixed fee for using the systems. The second approach is through a private implementing agency, the Infrastructure Development Company Limited (IDCOL), which sold the systems to households using a micro-finance scheme implemented by various private agencies, such as Grameen Shakti.

While the REB was able to provide SHS for about 12,000 households, the IDCOL reached over 320,000 households over the same period. The success of the micro-credit scheme lies mainly in the fact that ownership approach is more acceptable to rural households than the fee-for-service approach. Moreover, these private delivery agencies have more practical knowledge in providing micro-finance and greater reach at the community level. In particular, Grameen Shakti has played an important role in the dissemination of SHS in rural Bangladesh and its credit program has reached many low-income households (Asaduzzaman et al, 2008).

The key lesson from the Bangladesh experience is that while scaling-up the adoption of renewable energy technology depends critically on private sector participation, public support is critical at the initial stage, by means of financing, technical assistance and institution and human capacity building, until a critical mass is reached for scaling up SHS dissemination. Lessons from the Bangladesh case study can possibly be transferred to other countries while taking account of local conditions.

4. The 2005 Bangladeshi national survey

A national household survey was conducted in 2005 for monitoring and impact evaluation of the RERED project. Although this survey was conducted to study grid electrification impacts, it also collected information on SHS households, which allows us to undertake this study. In fact, this survey is nationally representative of the rural population and it is the first available large-scale national household survey that collects information on SHS purchases in developing countries where various donor-financed SHS programs have been implemented.

This survey covers 20,900 households in rural areas of all six administrative regions in Bangladesh, including 1,000 households who had purchased SHS under various subsidy programs implemented in rural Bangladesh since 2001. Table 1 summarizes the sample size and distribution of electricity access across the six administrative regions. Overall, about 62% of households have no electricity access, 6% with SHS and 31% with grid-electricity. Electricity access varies across regions, with the Barisal region having the highest concentration of non-electrified household at about 73%, while the Chittagong region has the lowest at 53%.

Kerosene use and its shares of nonfood and total spending by electricity access status and by income group are summarized in Table 2. On average, households without electricity access, use about 3 liters of kerosene per month for lighting while those with grid-electricity access use 2 liters, and with SHS use only 1 liter. The higher kerosene use among grid-connected households compared with households with SHS is likely due to the need to use kerosene for lighting back-up as a result of frequent outages of the grid-electricity.

The survey data also show that kerosene use accounts for a large proportion of household non-food expenditure, in particular among poor households. The average kerosene expenditure accounts for about 9% of total non-food budget among the bottom two deciles, in comparison to 3% for the top two income groups. Clearly, the financial benefits from a reduction in kerosene spending due to SHS installation would be larger for poor households. These benefits are in addition to other benefits, including better quality lighting and reduced health risks (indoor pollution) associated with kerosene lamps.

5. Carbon benefit, affordability and distributional impact of SHS programs

5.1 Quantifying the carbon benefit of SHS

The carbon benefits of SHS dissemination in rural areas come mainly from the fuel displacement, including kerosene, dry cell batteries, and diesel used for battery charging. In the analysis, we focus mainly on kerosene displacement due to data limitation on other fuel use. The current fuel use for lighting among households without access to grid-electricity is used as the energy baseline. This is consistent with the UNFCCC simplified procedures for small-scale clean development mechanism (CDM), which defines the energy baseline as the fuel consumption of the technology/device in use or would have been used in the absence of project activity.

5.1.1 Methodology

Quantifying the CO_2 impact from SHS installation involves the estimation of fuel displacement as a result of SHS installation. Two alternative methods are used to estimate the effect of SHS installation on kerosene: the regression approach and the Propensity Score Matching method (PSM).

The regression method allows one to estimate the net effect of electricity access on kerosene use controlling for observable household and village characteristics, as well as regional specific effects. The effect of electricity access on kerosene use is also interacted with the income variable to allow differential income effect. The econometric model is as follows:

$$Q_{hv} = \alpha + \beta X_{hv} + \lambda E_{hv} + \delta E_{hv} * I_{hv} + \sigma V_v + \gamma L + e_{hv}$$

where Q_{hv} is the quantity of kerosene used by household h in village v; X_{hv} household socio-economic characteristics; E_{hv} electricity is the dummy variable (taking the value 1 for access to electricity and 0 for no electricity); I_{hv} is the income of household h in village v; $\underline{V_v}$ is the village electrification variable (taking 1 if the household living in a village with grid-electricity, 0 in a village without grid-electricity); and $\underline{L}$ is the location variable which is a set of dummy variables for districts and sub-districts (i.e. upzila). This model is used to estimate the kerosene displacement effect separately for grid-electrification and SHS for comparison purposes.

One of the issues associated with the above model specification is the endogeneity of the choice of electricity access. It is often argued that household's decision to gain access to electricity (either connecting to grid in areas with existing grid network, or SHS in areas where SHS dissemination programs are implemented) is a choice variable. There likely exists a correlation between the choice of electricity access and other household characteristics, such as energy use preferences or household knowledge about the advantages and disadvantages of different fuel choices. If such household heterogeneity is not observable to analysts, i.e. they are omitted variables, and the estimated impact of electricity access on kerosene use by the regression method will be biased.

Unlike regression, PSM (propensity score matching) does not assume a functional relationship between the outcome and treatment variable. The PSM method involves matching households receiving treatment with control households that are similar in terms of their observable characteristics, and treatment effect is given by the difference of outcomes between these two groups of households. Matching is implemented by estimating the propensity score, which is the probability of treatment for each household based its observable characteristics (Rosenbaum and Rubin, 1983; 1985a, b). However, PSM also suffers from endogeneity bias as it cannot control for a household's unobservable characteristics which may influence its treatment and outcome. One solution to control for such endogeneity bias is to use instrumental variable (IV) regression. An instrumental variable (or instrument) is a variable which affects the treatment directly but the outcome only indirectly through the treatment. Finding a suitable instrumental is often difficult and we cannot identify one for SHS intervention in rural Bangladesh, and so IV method is not used here.[5] We assume that bias due to non-observable characteristics is not much.

In the context of this study, households who have installed SHS are matched with those who have a similar probability of purchasing a SHS based on observable household and community level characteristics, but have not installed SHS. The matching is confined to households living in non-electrified villages where SHS dissemination programs have been implemented. The probability of purchasing SHS, or the propensity score is estimated using a Probit model:

$$Prob\ (install\ SHS) = F(X_{hv,}\ L)$$

Where $X_{hv,}$ are the household characteristics and L is the dummy variable for location fixed effect.

The average treatment effect of SHS installation on kerosene use is estimated using the following:

$$Average\ Effect = E(Y1|D=1) - E(Y0|D=1)$$

[5] Khandker et al (2009) used an IV method to estimate the impact of grid-electricity access on income in rural Bangladesh using the same survey data. In their study, household distance to the cable line is used as an instrument.

Where $E(Y1 \mid D=1)$ and $E(Y0|D=1)$ are, separately, the average kerosene use among households that purchased SHS and those who have a similar probability of purchasing SHS based on observed covariates (X_{hv}, V_v, L), but have not installed SHS.

5.1.2 Kerosene displacement

Table 3 presents the estimated kerosene displacement using both regression and PSM methods. The displacement impact is statistically significant, indicating both SHSs and grid-electricity access reducing kerosene use. The impact of SHS access has a much larger impact on displacing kerosene than grid-electricity access. Focusing on the results from SHS, on average, the estimated kerosene displacement is about 2.7 liters/month by OLS (compared with 1.4 from grid-electricity connection) and 2.5 liter/month by PSM (1.5 from grid connection), after controlling for household socioeconomic factors, village electrification status and location effects. The scale of kerosene displacement increases with household incomes: about 2.3 liters per month being displaced for the bottom two income groups while for the top two groups displacement amount is about 3 liters.

The estimated displacement effect using the two methods is broadly consistent, although estimates from the PSM are slightly larger than that obtained from OLS. The standard errors associated with the estimates using the PSM method are substantially larger for the bottom and top two income groups than that using the OLS regression.

5.1.3 Avoided carbon emissions

The estimated kerosene displacement forms the base for quantifying the carbon emissions avoided from SHS dissemination. Using the carbon emission factor for kerosene (2.45 kg CO_2/liter), the avoided CO_2 emissions for the most commonly purchased SHS (40-50 Wp) is about 76 kg CO_2 per year in the context of rural Bangladesh. The study by Posorski et al (2002), using different method, shows that about 9 tons of CO_2 equivalent GHG emissions are avoided (which is equivalent to about 450 kg CO_2 per year) within a 20-year period of use of one SHS of 50 Wp compared with the baseline case.

The reported CO_2 emissions avoided from SHS from other countries, including the Bangladesh study, are summarized in Table 4. The estimate from the Bangladesh survey is significantly smaller than that reported in other studies (Ybema et al, 2000)[6], possibly due to two factors. First, the estimates from this study is based on a large scale household survey that allows the control for household socio-economic characteristics and location effects while other studies do not control confounding factors that may affect the kerosene use. Second, the Bangladesh study focuses only on kerosene displacement due to data limitation, but some studies reported in the table include multiple fuels (kerosene, dry cell batteries, and diesel used for battery charging).

While displacing kerosene use for lighting and diesel use for battery charging are the most direct carbon benefit, SHS dissemination can also avoid GHG emissions from new connection to grid-

[6] The estimated reduction is 3.9 liter/month from a smaller scale household survey (441 households) conducted by Grameen Shakti in 2009. Chaurey and Kandpal (2009) provide an estimate of 9.6 liter/month for rural households in India and the World Bank project report finds 19.6 liter/month displacement for rural households in Indonesia.

electricity. This is particularly relevant in the context of Bangladesh where the government has determined to use SHS as one of the alternatives to the grid option in its efforts to achieve the target of a universal access to electricity by 2020.

The grid electrification as an alternative baseline for quantifying the carbon benefit of SHS is also proposed in Kaufman et al (2000). Basically, the carbon benefits come from the comparison between two electrification options: grid connection using conventional fossil fuel and solar systems. It should be noted that the direct comparison can be problematic as there exists a substantial difference in the quality of electricity service received from the two options, with SHS providing much limited capacity.

In quantifying the carbon avoided using grid-electrification as an alternative baseline, the average level of electricity consumption of grid-connected household is proposed as the benchmark to estimate electrification generation (Kaufman et al, 2000). The underlying assumption is that non-electrified households would consume electricity at the same rate as the grid-connected households if they were connected to a grid. The availability of the Bangladesh household survey data allows us to predict the electricity consumption of non-electrified households based on the electricity consumption model estimated using the grid-connected households, controlling for household characteristics, such as incomes, family size and location.

The predicted average monthly electricity consumption among non-electrified households, based on this electricity model, is about 28 kwh per month when connected to a grid. The average consumption is about 26 kwh per month for the bottom two income groups and about 31kwh per month for the top two income groups. Using the grid-emission rate of 0.8 kg CO_2/kwh, the carbon emissions avoided from SHS is equivalent to about 269 kg CO_2 per SHS per year. This estimate is about 3.5 times that estimated using the kerosene displacement baseline (76 kg CO_2 per SHS per year).

The scale of the carbon emissions avoided from SHS adoption can be better illustrated by putting these estimates in the national context of total number of households currently without electricity access in Bangladesh (about 23.6 million households in 2008). If all non-electrified households were provided with SHS, the carbon emissions avoided from kerosene displacement per SHS per year would be equivalent to about 4% of total annual carbon emissions in Bangladesh in 2007. This figure will go up to about 15% if using the grid-electricity generation as the energy baseline to estimate the annual carbon benefit from SHS[7].

5.2 Assessing affordability

The cost of SHS is significant relative to household incomes in rural Bangladesh. The price of the most commonly installed SHS with a 40-50 Wp capacity was about $556 in Bangladesh in 2002, which was more than three times the rural household annual expenditure. The major

[7] The above estimated carbon benefit is not measured in terms of life cycle emissions. Using an input-output approach, Ganju and Mathur (2010) show that based on the comparative life cycle emissions, on an annual basis, solar powered LED lantern could results in a saving 93kg CO2, while CFL lantern 89 kg CO2 compared to a kerosene lantern.

barrier for SHS adoption is the large upfront cost. If micro-credit schemes are made available, SHS is likely to be an attractive option to many households in rural areas.

5.2.1 Cost comparison

In assessing affordability of SHS, it is instructive to compare the cost of different alternative energy options for lighting, including kerosene lamps, SHS and grid-electricity among non-electrified households. The monthly cost of the kerosene lamps is the observed spending collected in the survey. But the monthly cost of SHS or grid-electricity needs to be estimated.

The cost of SHS is estimated based on the exiting micro-credit scheme implemented in rural Bangladesh under the RERED project. Under such scheme, households were provided with a loan for a period of 3-5 years, at an annual interest rate of 12%, plus a $50 cash subsidy. Households who received the loan were required to pay upfront a down payment at the 10% of the total cost of SHS they purchase.

The monthly cost of SHS is thus imputed using the compound interest rate method with two assumptions imposed. First, all households living in non-electrified villages are entitled to the micro-credit scheme and a cash subsidy. Second, the household choice of SHS depends on its level of income which is based on information from the case study of the RERED project.[8] The cost of the grid-electricity option among non-electrified households is predicted based on the grid-electricity demand model estimated using the subsample of households connected to grid-electricity.

Table 5 presents the estimated monthly cost of three lighting options. The results show that, on average, the imputed monthly cost of SHS is about 7 or 5 times the cost of monthly spending on kerosene with a cash subsidy of $50 or $90. For the bottom two income groups, the monthly SHS cost is about 3.5 times the kerosene cost, while it is about 6.4 times the kerosene spending for the top two income groups.

The comparison of SHS with grid-electricity shows that the average monthly cost of SHS is about 3.4 times the cost of grid-electricity. In reality, however, SHS is not directly comparable with grid-electricity because of significant differences in the quality of services provided from the two electrification technologies.

[8] The case study of the RERED project shows that poor households tended to purchase SHS of lower capacity while better-off households opted for larger capacity SHS. Among the 320,000 SHSs installed by 2009, about 20% households chose a SHS of 40 Wp, 45% chose a SHS of 50 Wp, 20% in the range of 60-65 Wp and only 9% in the 85 Wp range. In estimating the monthly SHS cost, we assume that the bottom two deciles purchase only SHS of 20-30 Wp; the 3rd and 4th deciles purchase SHS of 40 Wp; 5th to 7th purchase SHS of 50 Wp, 8th and 9th for SHS 60-65 Wp and the top deciles purchase SHS of 85 Wp and above. Battery costs are assumed to range from Tk 3,200 to Tk 11,400, depending on the size of the SHS (RERED report). This amounts to about between 20-24% of a SHS price accordingly, which will be factored in the SHS prices.

5.2.2 Affordability

The average energy budget share among electrified households can be used as a benchmark against which the affordability of SHS is assessed[9]. The estimated energy (kerosene plus electricity) budget share among electrified households is about 2.3%. This is significantly lower than the budget share of about 8.4% for SHS based on the imputed monthly cost of SHS purchase.

However, given the fact for many households living in non-electrified villages, grid-electrification is unlikely to be an option for many years to come, the majority of households may well be willing to pay a substantial share of the budget for the option of SHS. The results from the probit model (presented in Annex Table A1) show that the propensity to purchase SHS is very sensitive to household incomes, with a 1% increase in per capita expenditure increasing the probability of installing SHS by about 12 %, and with a 1% increase in non-farm incomes increasing the probability by about 9%, holding other factors constant.

In the analysis, the criterion of a budget share of 8% is used to define affordability. That is, households are considered to be able to afford SHS under the existing micro-credit scheme if their budget share of monthly SHS financing is below the level of 8%. Admittedly, this level of budget share is high, so that the estimated affordability rate should be regarded as a upper bound estimate. By the criteria of 8% budget share, the total number of households in rural areas that can afford SHS is about 76,000 households under the existing micro-credit scheme plus a $50 cash subsidy, representing about 24% of non-electrified households in the sample districts. This number goes up to about 45% if the cash subsidy increases to $90 (see Figure 1).

The spatial distribution of households who can afford SHS is also important as it provides useful insights into the potential for cost reduction in SHS dissemination from economies of scale. The district level affordability rate and the proportion of non-electrified households are presented in the Annex Table A2. Among the 42 districts in the sample, 17 districts have an affordability rate above 25%. More importantly, the 17 districts also have a relatively high concentration of households living in non-electrified villages at the level of 45% compared with the national average of 38%.

The spatial analysis indicates that the potential market for scaling up SHS indeed exists in many parts of the rural areas in Bangladesh if well-designed micro-finance schemes and delivery services can be implemented successfully. The cost of SHS dissemination, including distribution and post-purchase maintenance cost, can also be reduced substantially because of scale of the market.

5.3 Distributional impact analysis of SHS subsidies

While the SHS programs financed through public resources have been implemented in many low-income countries over the past decade, the distributional consequences of SHS promotion programs are not well studied. The general belief based on anecdote evidence is that SHS

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[9] The study for housing affordability for California uses the budget share of 30% as the benchmark and households with a housing spending budget share above 30% are defined not able to afford (name)

subsidies are not pro-poor because the better-off households capture the subsidies disproportionally. Consequently, expanding rural electrification from SHS programs is not considered to be an effective policy choice for addressing poverty issues, although little empirical evidence exists to validate such claims. The Bangladesh national survey data presents an opportunity to empirically analyze the distributional impact of SHS programs.

5.3.1 Policy simulation

The distributional consequences are illustrated using a policy simulation exercise under two assumptions. First, all households currently without grid-electricity are assumed to be entitled to the micro-finance scheme. Second, the private sector agencies who are responsible for implementing the SHS decide program locations at the upzila level. The choice of location is driven by the objective of maximizing SHS dissemination while minimizing the operational cost. Two indicators at the upzila level that are important from the perspective of delivery agencies include: (1) the affordability rate, and (2) the proportion of households living in non-electrified villages, both capturing the SHS market potential as well as the scale of the operational cost.

The distributional consequences are essentially determined by the location choices of the private sector delivery agencies. For example, the implementing agencies may choose to place SHS programs only in locations with a high affordability rate. But it is also likely that these locations have a high concentration of better-off households, in which case the SHS programs will be regressive because better-off households would receive the subsidies disproportionally.

5.3.2 Distributional impact

The distributional impact of SHS promotion program is analyzed using the concentration curve (CC). The CC plots the cumulative percentage of the SHS subsidies received by households against the cumulative percentage of household population, ranked by per capita income in ascending order. [10] Therefore, the CC graphically illustrates the share of program subsidies captured by different incomes groups.

The distributional impact of the policy simulation based on the two location choice indicators are presented in Figure 2. Clearly, targeting SHS programs based either on affordability rate or the proportion non-electrified households at the district level will be progressive. As expected, the location choice based on the latter is more equitable, with the bottom 30% of households receiving about 55% of total subsidies, while they only receive about 45% if the targeting is based on the affordability rate. The Annex Table A3 presents a summary of statistics that measure the distribution of SHS subsidies across income distribution as well as the average subsidies received by each decile.

[10] If the CC lies above the 45 degree line of equality, the allocation of subsidies is progressive, with the poor households capturing the total subsidies disproportionately and vice versa if it lies below the equality line. The CC can also be used to compare different policy options - If one concentration curve lies everywhere above another one, the first curve is said to dominate the second one, in the sense that the first curve represents a more progressive policy option than that second one.

The positive distributional consequences of targeted SHS programs from the simulation result mainly from the fact that the concentration of non-electrified households and the poverty rate are closely correlated across districts. In Figure 3, the poverty map which is constructed based on household consumption per capita [11]is contrasted with the map of concentration of non-electrified households at the upzila level, which reveals the strong spatial overlap between the two indicators.

Improving the efficiency and equity of SHS projects requires better project targeting as well as better integration of renewable energy projects with existing development projects on the ground. To this end, it useful to overlay the location choice indicators for SHS program delivery with the poverty map to target SHS programs. For example, SHS programs should be placed in localities where the affordability rate is sufficiently high and where there also exist poverty alleviation programs to avoid duplication while maximizing the impact through resource pooling and coordination. Yet, so far, many of the SHS programs have been implemented in isolation, with little attention being paid to the integration into the existing social program operated at the local level. With the rapid increase in carbon finance for climate mitigation projects in developing countries, the issue with regard to how renewable energy projects should be targeted and integrated with poverty programs should, therefore, be highlighted in the policy-making in order to maximize the carbon mitigation and development impact.

6. Conclusions

Using the Bangladesh national household survey, this study provides three key findings. First, dissemination of SHS for rural electrification can generate substantial carbon benefit in the context of rural Bangladesh. The annual carbon avoided from kerosene displacement as a result of SHS installation would be equivalent to about 4% of total annual carbon emissions in Bangladesh in 2007 if all households without electricity access were provided with SHS. This figure will go up to about 15% if the grid-electricity generation is used as the energy baseline to estimate the carbon benefit from SHS.

Second, under the assumption that the existing micro-credit scheme plus a cash subsidy is made available to all non-electrified households in rural Bangladesh, the affordability assessment indicates that scaling-up SHS adoption is indeed possible in many parts of rural areas. Among the 41 districts in the survey, about 17 districts have an affordability rate over 25% as well as high concentration of non-electrified households in comparison to the national average. This means there exists a potential market for SHS and it is also possible to reduce the costs of SHS dissemination due to economies of scale to promote a profitable participation of the private sector in the SHS market.

Third, contrary to the commonly held views that subsidies for promoting SHS dissemination in rural areas benefit mainly better-off households, our policy simulation shows that SHS subsidies in rural Bangladesh are progressive when programs are appropriately targeted even using the private sector delivery model.

[11] The 2005 poverty map is constructed using the 2005 Household Living Standard survey by the World Bank.

Two policy messages emerge from this study. First, the Bangladesh experience shows that while the potential for scaling-up SHS in rural areas exists if the upfront cost of SHS can be addressed through improving access to micro-credit in combination with cash subsidies, the real challenges lie in how these programs can be implemented on the ground. The success of the SHS dissemination in rural Bangladesh depends critically on active public support, in particular at the initial stage of the operation. These supports should include financing, technical assistance, SHS information dissemination and the development of the institutional capacity and human resources at the community level.

Second, the rapid increase in financial resources channeled to climate mitigation, in particular in the clean energy sector, presents an opportunity to integrate renewable energy projects with social development projects to reinforce synergies between climate change mitigation and development. This means efforts must focus on improving the efficient and equitable allocation of carbon finance to projects that generate the largest carbon and development benefits. At the project level, the design and implementation of renewable energy projects should focus on issues such as targeting, integration and coordination with existing poverty alleviation program in order to maximize the carbon mitigation and development benefit.

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Table 1: Household electricity access by region

Region	HH living in non-electrified village %	HH with no electricity (%)	HH with SHS (%)	HH with grid-electricity (%)	Number of HH
Barisal	43.9	73.0	7.8	19.2	3,100
Chittagong	40.9	53.7	8.7	37.7	4,024
Dhaka	46.1	63.1	5.7	31.3	4,045
Khulna	42.8	59.4	7.5	33.1	3,183
Rajshahi	43.5	65.0	5.2	29.9	3,898
Sylhet	38.9	62.4	2.2	35.4	2,663
Total	43.2	62.2	6.4	31.5	20,913

Table 2: Monthly kerosene use by household electricity access

	Quantity (liter)	Cost (Tk)	Share of nonfood (%)	Share of total expenditure (%)	Number of HH
Electricity status					
no electricity	3	75	8.3	2.2	10175
has SHS	1	25	0.8	0.4	952
has grid-electricity	2	48	3.2	1.0	9786
Expenditure Decile					
1	2	52	9.2	2.4	1999
2	2	60	8.2	2.1	2025
3	2	56	7.3	1.9	2096
4	2.5	70	6.9	1.8	2077
5	3	72	6.4	1.8	2123
6	3	72	6.1	1.7	2116
7	3	72	5.5	1.6	2089
8	2	60	4.6	1.4	2092
9	2	56	3.7	1.2	2105
10	2	56	2.2	0.9	2192
Total	2	60	6.0	1.7	20914

Note: Both the quantity and cost are median

Table 3: Impact of electricity access on kerosene use: Grid electricity and SHS

Expenditure per capita	kerosene use (monthly)	Grid-electricity				SHS			
		OLS		PSM		OLS		PSM	
	(liter)	Estimate	(s.e.)	Estimate	(s.e.)	Estimate	(s.e.)	Estimate	(s.e.)
Ave effect	2.8	-1.4	*0.0*	-1.5	*0.2*	-2.7	*0.1*	-2.5	*0.1*
by deciles									
1	2.7	-1.1	*0.0*	-1.1	*0.3*	-2.3	*0.2*	-2.4	*0.5*
2	2.8	-1.2	*0.1*	-1.3	*0.4*	-2.1	*0.3*	-2.3	*0.6*
3	2.8	-1.3	*0.1*	-0.8	*0.5*	-2.3	*0.3*	-2.4	*0.3*
4	2.9	-1.3	*0.1*	-2.9	*0.9*	-2.5	*0.2*	-2.6	*0.2*
5	2.9	-1.4	*0.1*	-0.7	*0.3*	-2.6	*0.2*	-2.8	*0.1*
6	3.0	-1.4	*0.1*	-1.4	*0.7*	-2.6	*0.2*	-2.9	*0.2*
7	2.9	-1.5	*0.1*	-1.4	*0.5*	-2.7	*0.2*	-3.1	*0.2*
8	2.9	-1.6	*0.1*	-1.7	*0.5*	-2.7	*0.2*	-3.1	*0.2*
9	2.8	-1.6	*0.1*	-2.7	*0.8*	-3.0	*0.2*	-3.8	*0.8*
10	2.6	-1.7	*0.1*	-0.7	*0.7*	-2.8	*0.2*	-3.1	*0.3*

Note: The monthly kerosene use is the median measure for HH without electricity.
PSM refers to propensity score matching method.

Table 4: Reported CO_2 emissions avoided per SHS

country	founding scheme SHS model	SHS model (Wp)	Emission reduction
			(kg CO_2/yr)
Argentina	Global environment facility	50-400	504
Honduras	Activities implemented jointly	30-60	246
India	Commercial carbon offset funding	20-53	373
Indonesia	World Bank/GEF	50	448
Nepal	Government of Nepal	35	79
Kenya	Commercial cash sales	12 to 50	205
South Africa	Shell/Eskom fee for service	50	230
Swaziland	IVAM/ECN triodos commercial credit	50	125
REPP report		10 to 50	150-300
Bangladesh	**World Bank/GEF**	**40 to 50**	**76**

Note: The table is taken from a paper by Chaurey and Kandpal. The Bangladesh estimate is estimated by authors from the 2005 household survey

Table 5: Monthly cost comparison: SHS, kerosene and grid-electricity

Expenditure deciles	Kerosene	Grid-electricity	SHS $50 subsidy	SHS $90 subsidy	Energy expenditure share % (kerosene+ electricity)	Energy expenditure share % SHS ($90 subsidy)
Average	75	132	459	397	2.2	8.4
1	60	107	214	153	2.7	6.5
2	72	118	214	153	2.3	5.3
3	72	124	306	244	2.3	7.7
4	75	128	306	244	2.2	6.8
5	78	135	459	397	2.1	10.1
6	84	138	459	397	2.1	10.5
7	84	141	459	397	2.0	9.6
8	84	149	612	550	1.9	12.0
9	100	155	612	550	1.8	10.8
10	100	169	860	799	1.6	12.9

Note: SHS prices are taken from the project report, ranging from Tk 13,000 ($190) for SHS of 20-30 Wp to Tk 41,900 ($612) for SHS of 85 Wp

Figure 1: Affordability of SHS by households under different subsidy schemes

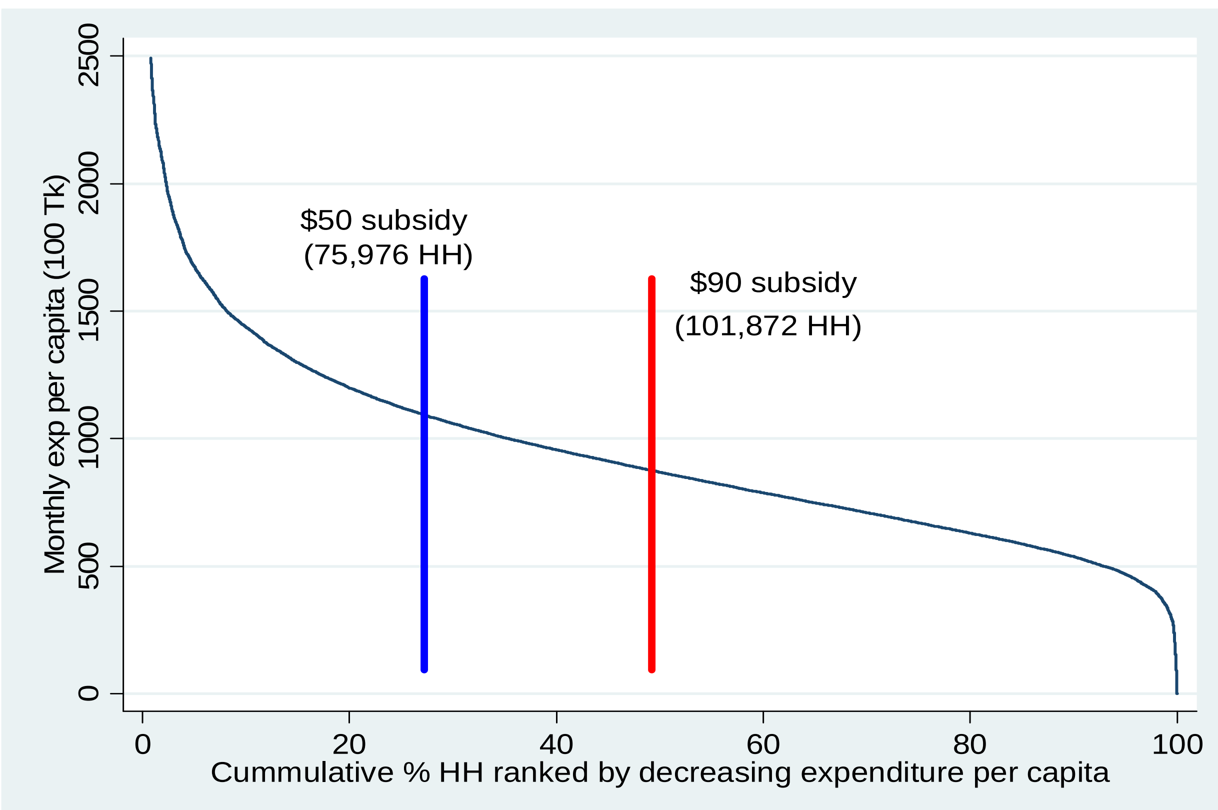


Figure 2: Distributional effects of SHS location selection strategies

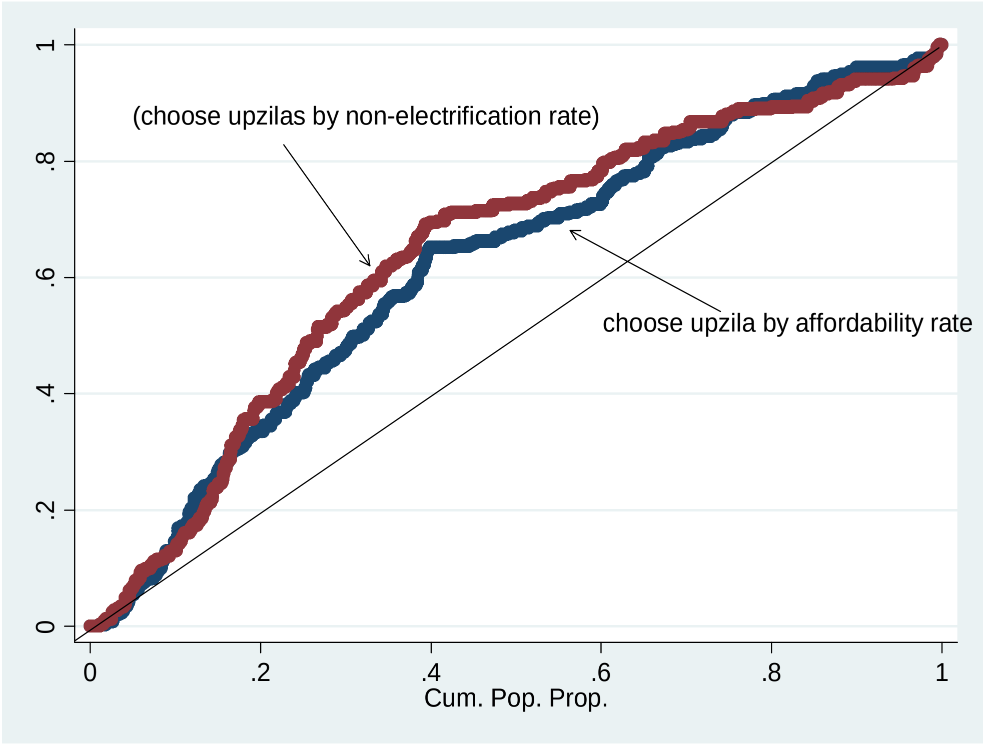
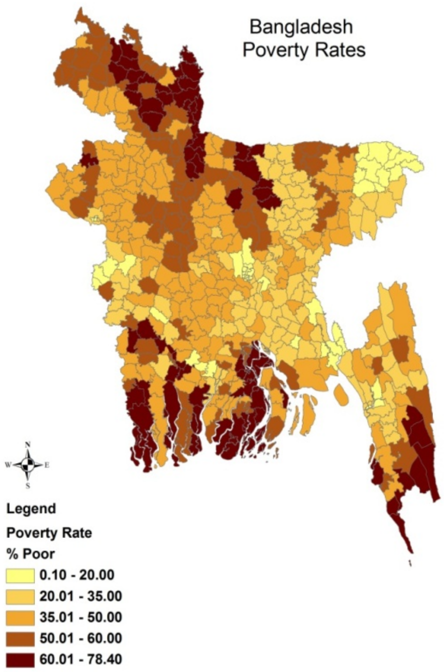
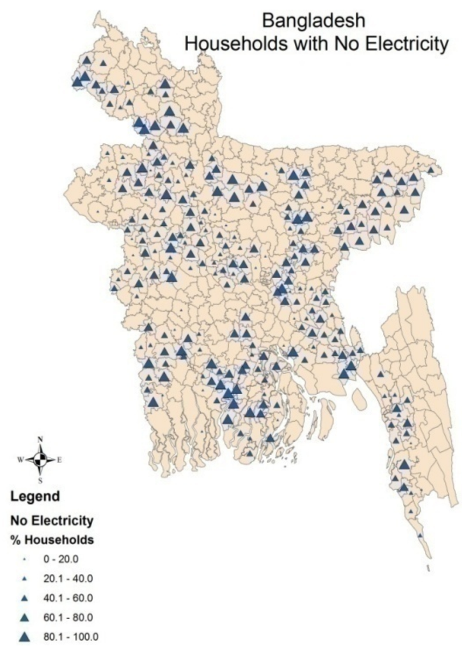


Figure 3: Upzila level poverty and non-electrification rates in Bangladesh





Annex

Table A1: Probability of SHS purchase among households without electricity

Number of obs = 6074
Wald chi2(38) = 922.34
Prob > chi2 = 0.0000

Log likelihood=-1746.45 **Pseudo R2 = 0.3142**

SHS purchase	dF/dx	Std. Err.	z	P>|z|	x-bar	[95% C.I.]	
Log(per capita expenditure)	0.12	0.01	11.0	0.00	9.26	.094753	.138631
Log(land size)	0.05	0.00	15.5	0.00	4.03	.044682	.057767
Non-farm income	0.09	0.01	7.9	0.00	0.64	.067507	.111763
Household size	0.01	0.00	4.9	0.00	4.79	.006093	.014466
Female head	0.02	0.01	1.9	0.06	0.96	.002914	.045587
Location dummy variables	included						

Note: Full specification includes location effects that are not reported here.

Table A2: Affordability rate and rate of non-electrified households at district level

($50 cash subsidy and micro-finance scheme)

District Name	Households Afford SHS (%)	Non-electrified Households (%)
Cox's Bazar	54	43
Sylhet	44	32
Narayanganj	42	28
Habiganj	40	40
Mymensingh	38	39
Kishoreganj	36	85
Noakhali	34	38
Tangail	33	38
Netrokona	33	79
Narsingdi	31	29
Feni	31	30
Madaripur	29	28
Thakurgaon	28	23
Moulvibazar	27	37
Chandpur	27	42
Chittagong	27	36
Pabna	27	36
Bagerhat	26	44
Rangpur	24	45
Comilla	23	32
Bogra	23	49

District Name	Households Afford SHS (%)	Non-electrified Households (%)
Lakshmipur	23	30
Gaibandha	22	67
Pirojpur	22	32
Naogaon	20	48
Sirajgonj	20	35
Jessore	19	36
Narail	19	59
Jamalpur	19	67
Satkhira	19	38
Rajshahi	18	20
Dinajpur	18	34
Natore	16	26
Dhaka	15	26
Barisal	15	37
Joypurhat	13	48
Patuakhali	12	47
Kushtia	12	21
Gazipur	11	41
Barguna	10	3
Manikganj	10	23
Chuadanga	7	51
Meherpur	5	17
Total	24	36

Table A3: Distributional analysis of SHS subsidies

Expenditure Deciles	Target by non-electrification rate		Target by affordability rate	
	Subsidy	share(%)	Subsidy	share(%)
1	270.2	19.2	214.5	15.2
2	273.4	18.5	300.6	20.3
3	204.1	14.0	161.7	11.1
4	168.9	11.4	177.8	12.0
5	92.3	6.1	96.2	6.4
6	109.6	7.1	165.7	10.7
7	102.4	6.5	110.4	7.0
8	53.9	3.4	64.4	4.1
9	103.6	6.4	106.5	6.6
10	110.1	7.3	99.2	6.6
Total	151.2	10.2	151.3	10.1